

[DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION]

GATE DRIVING CIRCUIT OF SEMICONDUCTOR SWITCHING DEVICE

[WHAT IS CLAIMED IS]

[Claim 1] A gate driving circuit for use in an insulated gate type semiconductor switching device (11), comprising:

a switching device for turn-on (18) operable to be turned on when turning on the insulated gate type semiconductor switching device (11);

a switching device for turn-off (20) operable to be turned on when turning off the insulated gate type semiconductor switching device (11);

a DC voltage source (12) that has a first output terminal (12a) supplying an on-voltage to a gate electrode of the insulated gate type semiconductor switching device (11) and a second output terminal (12b) supplying an off-voltage to the gate electrode, and can change a level of the on-voltage output from at least the first output terminal (12a);

a gate resistor for turn-on (19) that is connected between the first output terminal (12a) of said DC voltage source (12) and the gate electrode of the insulated gate type semiconductor switching device (11) in a state where said switching device for turn-on (18) has been turned on;

a gate resistor for turn-off (21) that is connected between the second output terminal (12b) of said DC voltage source (12) and the gate electrode of the insulated gate type semiconductor switching device (11) in a state where said switching device for turn-off (20) has been turned on;

a voltage detecting means (22) operable to detect a gate voltage of the insulated gate type semiconductor switching device (11); and

a gate control means (23) that is provided to selectively turn on said switching device for turn-on (18) and said switching device for turn-off (20) based on a gate controlling timing signal, and changes the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) according to the detected voltage level of said voltage detecting means (22) when turning on said switching device for turn-on (18).

[Claim 2] The gate driving circuit of the semiconductor switching device as claimed in claim 1, wherein said gate control means (23) temporarily reduces the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) while the gate voltage detected by said voltage detecting means (22) is between a first set value and a second set value having a value higher than the first set value in a state where said switching device for turn-on (18) has been turned on.

[Claim 3] The gate driving circuit of the semiconductor switching device as claimed in claim 2, wherein

said voltage detecting means (22) detects a state where the rate of change of the gate voltage of the insulated gate type semiconductor switching device (11) is temporarily reduced by a mirror effect, and

the second set value is set for the gate voltage at the time point at which said voltage detecting means (22) detects a temporary fall of the rate of change of the gate voltage.

[Claim 4] The gate driving circuit of the semiconductor switching device as claimed in claim 3, wherein said voltage detecting means (22) detects the state where the rate of change of the gate voltage of the insulated gate type semiconductor switching device (11) is temporarily reduced by a mirror effect based on a derivative value of the gate voltage.

[Claim 5] The gate driving circuit of the semiconductor

switching device as claimed in claim 1, wherein said gate control means (23) temporarily reduces the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) by a predetermined time after the gate voltage detected by said voltage detecting means (22) reaches a first set value in a state where said switching device for turn-on (18) has been turned on.

[Claim 6] The gate driving circuit of the semiconductor switching device as claimed in claim 5, wherein said gate control means (23) terminates the control temporarily reducing the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) after a load current flowing into the insulated gate type semiconductor switching device (11) reaches a peak value.

[Claim 7] The gate driving circuit of the semiconductor switching device as claimed in any of claims 2 to 6, wherein the first set value is set to be equivalent to a gate threshold value voltage of the insulated gate type semiconductor switching device (11).

[Claim 8] A gate driving circuit for use in an insulated gate type semiconductor switching device (11), comprising:

- a switching device for turn-on (18) operable to be turned on when turning on the insulated gate type semiconductor switching device (11);

- a switching device for turn-off (20) operable to be turned on when turning off the insulated gate type semiconductor switching device (11);

- a DC voltage source (12) that has a first output terminal (12a) supplying an on-voltage to a gate electrode of the insulated gate type semiconductor switching device (11) and a second output terminal (12b) supplying an off-voltage to the gate electrode,

and can change a level of the on-voltage output from at least the first output terminal (12a);

a gate resistor for turn-on (19) that is connected between the first output terminal (12a) of said DC voltage source (12) and the gate electrode of the insulated gate type semiconductor switching device (11) in a state where said switching device for turn-on (18) has been turned on;

a gate resistor for turn-off (21) that is connected between the second output terminal (12b) of said DC voltage source (12) and the gate electrode of the insulated gate type semiconductor switching device (11) in a state where said switching device for turn-off (20) has been turned on; and

a gate control means (25) that is provided to selectively turn on said switching device for turn-on (18) and said switching device for turn-off (20) based on a gate controlling timing signal, and changes the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) after a predetermined time has elapsed from the time point at which said switching device for turn-on (18) is turned on.

[Claim 9] The gate driving circuit of the semiconductor switching device as claimed in claim 8, wherein said gate control means (25) temporarily reduces the level of the on-voltage output from the first output terminal (12a) of said DC voltage source (12) for a predetermined period after a predetermined time has elapsed from the time point at which said switching device for turn-on (18) is turned on.

[Claim 10] The gate driving circuit of the semiconductor switching device as claimed in any of claims 1 to 9, wherein said DC voltage source (12) comprises:

a plurality of voltage sources (13, 14) that is used for generating the on-voltage; and

switching devices for voltage switching (16, 17) that change the level of the on-voltage output from the first output terminal (12a) by selectively validating these voltage sources (13, 14).

[Claim 11] The gate driving circuit of the semiconductor switching device as claimed in claim 10, wherein

the plurality of voltage sources (13, 14) has an output voltage level different from each other, and

the switching devices for voltage switching (16, 17) change the level of the on-voltage by connecting one of the plurality of voltage sources (13, 14) to the first output terminal (12a).

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field of the Invention]

The present invention relates to a gate driving circuit for use in an insulated gate type semiconductor switching device such as an IGBT or a MOSFET.

[0002]

[Problems to be solved by the Invention]

Fig. 5 shows a basic circuit configuration example of an inverter device for driving an AC motor by variable speed. In Fig. 5, an inverter main circuit 1 is configured by connecting six semiconductor switching devices 2a to 2f consisting of IGBT in three-phase bridge method. The inverter main circuit 1 generates an AC output of a variable voltage and a variable frequency to supply it to the AC motor 5 by switching an output of a DC power source 4 supplied through a smoothing capacitor 3. These semiconductor switching devices 2a to 2f are turned on or off in a predetermined mode by means of a gate control signal from a gate control circuit 6, and are respectively connected to circulating diodes 7a to 7f in parallel with each

other.

[0003] In such a circuit configuration, for example, in order that the state (in which the semiconductor switching devices 2a and 2d are turned on) in which a current flows in the direction as shown by the arrow A in Fig. 5 is changed into the state in which a current flows in the direction as shown by the arrow B, when the semiconductor switching devices 2a and 2d are changed into an off state and the semiconductor switching devices 2b and 2e are changed into an on-state, the sudden change of a current is caused on the semiconductor switching devices 2b and 2e and the circulating diodes 7a and 7d. However, such a sudden current causes the generation of a current surge and noise and a switching loss, and causes the destruction and degradation of the semiconductor switching device or the circulating diode in some cases.

[0004] On the other hand, for example, Japanese Patent Laid-Open No. 1998-23743 discloses a driving circuit of a semiconductor device that includes a plurality of driving voltage sources (e.g., two sources) for supplying a gate voltage to an IGBT device and a switching means for switching these driving voltage sources during turning off the IGBT device. The object of Japanese Patent Laid-Open No. 1998-23743 is to restrain a voltage surge and reduce a switching loss during switching the IGBT device. However, since the driving circuit of the semiconductor device works only during turning off the IGBT device, the driving circuit cannot solve the above-described problem created by a circuit configuration such as Fig. 5.

[0005] The present invention has been achieved in view of the situation above, and the object is to provide a gate driving circuit of a semiconductor switching device that can reduce a switching loss and prolong a device life while restraining the

generation of a current surge and a noise during turning on an insulated gate type semiconductor switching device.

[0006]

[Means for Achieving the Objects]

[0016]

[0017]

[Embodiments of the Invention]

(The first preferred embodiment)

Hereinafter, the first example of the present invention would be described in conjunction with Figs. 1 to 3. In Fig. 1 showing a total electric configuration, an IGBT 11 is an insulated gate type semiconductor switching device in which a conducting state between its collector and its emitter is controlled by a gate voltage being applied to its gate electrode. In the drawings, capacity  $C_{gc}$  between its gate and its collector and capacity  $C_{ge}$  between its gate and its emitter are shown as an equivalent circuit.

[0018] A DC voltage source 12 generates a positive on-voltage to turn on the IGBT 11 and a negative off-voltage to turn off the IGBT 11, and has a first output terminal 12a for an on-voltage output and a second output terminal 12b for an off-voltage output. In this case, the DC voltage source 12 is configured so that a level of the on-voltage output from the first output terminal 12a can be changed with two steps. For example, the DC voltage source 12 has a circuit configuration as shown in Fig. 2.

[0019] In other words, in Fig. 2, the DC voltage source 12 includes three voltage sources 13, 14, and 15, and switching devices for voltage switching 16 and 17 of which only one side is selectively turned on. At least the voltage sources 13 and 14 have an output voltage level different from each other. Then,

in the voltage sources 13 and 14, their positive electrode side terminals are connected to the first output terminal 12a via the switching devices for voltage switching 16 and 17 individually, and their negative electrode side terminals are connected to a ground terminal. Moreover, in the voltage source 15, its negative electrode side terminal is connected to the second output terminal 12b and its positive electrode side terminal is connected to the ground terminal. In addition, each of the switching devices 13 and 15 consists of semiconductor switching devices (FET, a bipolar transistor, and so on).

[0020] In the DC voltage source 12 having such a configuration, for example, assuming that the voltages between the terminals of the voltage sources 13, 14, and 15 are  $V_{13}$ ,  $V_{14}$ , and  $V_{15}$  ( $V_{13} > V_{14}$ ) respectively, either of the positive on-voltages  $+V_{13}$  and  $+V_{14}$  is output from the first output terminal 12a according to an ON state of the switching devices for voltage switching 16 and 17, and the negative off-voltage  $-V_{15}$  is output from the second output terminal 12b.

[0021] Referring to Fig. 1, a switching device for turn-on 18 and a gate resistor for turn-on 19 are serially connected between the first output terminal 12a of the DC voltage source 12 and the gate electrode of the IGBT 11, and a switching device for turn-off 20 and a gate resistor for turn-off 21 are serially connected between the second output terminal 12b of the DC voltage source 12 and the gate electrode of the IGBT 11. In addition, each of the switching devices 18 and 20 consist of a semiconductor switching devices (FET, a bipolar transistor, and so on). Moreover, the gate resistor for turn-on 19 and the gate resistor for turn-off 21 can be made with one resistor.

[0022] A gate voltage detecting circuit 22 (equivalent to a voltage detecting means of the present invention) is provided



in order to detect a gate voltage of the IGBT 11, and has a configuration supplying the detected voltage to a control circuit 23 (equivalent to a gate control means of the present invention). A gate signal generating circuit 24 generates a gate controlling timing signal to control on/off states of the IGBT 11 in a predetermined mode, and supplies the gate controlling timing signal to the control circuit 23.

[0023] The control circuit 23 selectively turns on the switching device for turn-on 18 and the switching device for turn-off 20 based on the gate timing signal from the gate signal generating circuit 24. More particularly, when turning on the switching device for turn-on 18, the control circuit 23 selectively turns on either of the switching devices for voltage switching 16 and 17 in the DC voltage source 12 in order to control the change of a level of an on-voltage output from the first output terminal 12a of the DC voltage source 12, based on the voltage level detected by the gate voltage detecting circuit 22.

[0024] Hereinafter, the control and operation by the control circuit 23 will be described referring to the characteristic curves shown in Fig. 3. In addition, Fig. 3 schematically shows variation character of a gate voltage  $V_{ge}$  of the IGBT 11, a voltage  $V_{ce}$  between the collector and the emitter, and a collector current  $I_c$  (a load current).

[0025] The control circuit 23 turns on the switching device for turn-on 18 when the gate controlling timing signal from the gate signal generating circuit 24 shows that the IGBT 11 is an on-state. At this time, the switching device for voltage switching 16 in the DC voltage source 12 has been turned on previously. For this reason, since an on-voltage ( $=+V_{13}$ ) corresponding to a terminal voltage of the voltage source 13

is output from the first output terminal 12a of the DC voltage source 12, the on-voltage is applied to the gate electrode of the IGBT 11 through the gate resistor for turn-on 19 (at the timing  $t_1$  shown in Fig. 3). When the gate voltage  $V_{ge}$  according to the application of such an on-voltage becomes larger than a gate threshold value voltage  $V_{th}$  of the IGBT 11 (at the timing  $t_2$ ), the collector current  $I_c$  begins to flow and also the collector/emitter voltage  $V_{ce}$  begins to fall.

[0026] After that, the control circuit 23 decides a time point (timing  $t_3$ ) at which the gate voltage  $V_{ge}$  reaches a first preset set value  $V_{s1}$  based on the voltage detected by the gate voltage detecting circuit 22, and turns off the switching device for voltage switching 16 and also turns on the switching device for voltage switching 17 in the DC voltage source 12. In this way, since an on-voltage ( $=+V_{14}<+V_{13}$ ) corresponding to a terminal voltage of the voltage source 14 is output from the first output terminal 12a of the DC voltage source 12, a level of the on-voltage applied to the gate electrode of the IGBT 11 is changed into a fallen state.

[0027] After changing such an on-voltage, the control circuit 23 decides a time point (timing  $t_4$ ) at which the gate voltage  $V_{ge}$  reaches a second preset set value  $V_{s2}$  based on the voltage detected by the gate voltage detecting circuit 22. In this case, the second set value  $V_{s2}$  can be set as an absolute value. However, when turning on the IGBT 11, the control circuit 23 may detect a state in which the rate of change of the gate voltage  $V_{ge}$  is temporarily reduced by a mirror effect based on the voltage detected by the gate voltage detecting circuit 22, and decide that the gate voltage  $V_{ge}$  reaches the second set value  $V_{s2}$  under such a detection state.

[0028] Then, when the control circuit 23 decides that the

gate voltage  $V_{ge}$  has reached the second set value  $V_{s2}$ , the control circuit 23 returns the state of the switching device for voltage switching 16 in the DC voltage source 12 to an on-state so that the on-voltage ( $=V_{13}$ ) corresponding to the terminal voltage of the voltage source 13 is output from the first output terminal 12a. In this way, the level of the on-voltage applied to the gate electrode of the IGBT 11 is returned from the fallen state to an original state, and finally the IGBT 11 has a completely turned-on state (a state in which the voltage  $V_{ce}$  between the collector and the emitter is substantially zero).

[0029] After that, when the control circuit 23 receives the gate controlling timing signal to turn off the IGBT 11 from the gate signal generating circuit 24, the control circuit 23 turns on the switching device 20 for turn-off in place of the switching device for turn-on 18. For this reason, since a negative off-voltage ( $=-V_{15}$ ) is output from the second output terminal 12a of the DC voltage source 12, the off-voltage is applied to the gate electrode of the IGBT 11 through the gate resistor for turn-off 21 (at the timing  $t_5$  shown in Fig. 3). According to the application of such an off-voltage, the IGBT 11 is finally turned off.

[0030] In brief, according to a configuration of the above-described present embodiment, the effect as described below will be obtained. In other words, when turning on the IGBT 11, since the level of the gate voltage is changed into a low state by a predetermined period by an appropriate control, a charging current flowing into capacity  $C_{ge}$  between the gate and the emitter of the IGBT 11 is restricted. As a result, since raising the gate voltage  $V_{ge}$  of the IGBT 11 is constrained while the gate voltage level has been changed as described above,  $di/dt$  (that is, the rate of rise) of the collector current  $I_c$  (a load

current) flowing into the IGBT 11 becomes gentle. In this way, since the collector current  $I_c$  does not suddenly flow during turning on the IGBT 11, it is possible to reduce the switching loss, to prevent the destruction and degradation of the IGBT 11, and to prolong a life thereof while restraining the generation of a current surge and a noise. In addition, it is also possible to prevent the destruction and degradation of a circulating diode when the circulating diode is provided in addition to the IGBT 11.

[0031] Moreover, when turning on the IGBT 11 as discussed above, since the level of the gate voltage  $V_{ge}$  is changed into a low state based on the voltage detected by the gate voltage detecting circuit 22 and the preset first set value  $V_{s1}$  and second set value  $V_{s2}$ , such a control can surely be performed for a predetermined period. In this case, since the second set value  $V_{s2}$  is set to the gate voltage  $V_{ge}$  at time point at which the rate of change of the gate voltage  $V_{ge}$  is temporarily reduced by a mirror effect, for example, during turning on the IGBT 11, it is possible to easily detect whether the gate voltage  $V_{ge}$  reaches the second set value  $V_{s2}$ .

[0032] Since the DC voltage source 12 to generate an on-voltage to be applied to the gate of the IGBT 11 includes the plurality of voltage sources 13 and 14 for generating the on-voltage and the switching devices for voltage switching 16 and 17 to change the level of the on-voltage output from the first output terminal 12 by selectively validating these voltage sources 13 and 14, it is possible to easily change the level of the on-voltage by controlling the switching devices for voltage switching 16 and 17.

(The second preferred embodiment)

[0033] Fig. 4 shows the second example of the present

invention. Hereinafter, only parts different from those of the first example will be described. In other words, in the second example, the gate voltage detecting circuit 22 described in the first example (see Fig. 1) is omitted, and a control circuit 25 (equivalent to a gate control means of the present invention) is provided in place of the control circuit 23 in the first example. The control circuit 25 selectively turns on the switching device for turn-on 18 and the switching device for turn-off 20 based on the gate timing signal from the gate signal generating circuit 24, and when turning on the switching device for turn-on 18, also reduces the level of the on-voltage output from the first output terminal 12a of the DC voltage source 12 by a predetermined period after a predetermined time from the turned-on point.

[0034] Such a control reducing the level of the on-voltage by a predetermined period is performed by serially changing an on-state of the switching devices for voltage switching 16 and 17 (see Fig. 2) in the DC voltage source 12. Specifically, the on-voltage +V13 is output by means of the switching device for voltage switching 16 that is already turned on at the time point at which the switching device for turn-on 18 is turned on, the on-voltage +V14 is output by turning on the switching device for voltage switching 17 in place of the switching device for voltage switching 16 at the time point at which a predetermined time has elapsed after that, and then the on-voltage +V13 is output by turning on the switching device for voltage switching 16 again after the predetermined time.

[0035] The configuration of the second example also has the same effect as that of the first example. Particularly, according to the second example, since the control changing the level of the on-voltage is performed by the only time control, it is possible to simplify the whole configuration of the circuit

due to omission of the gate voltage detecting circuit 22.

(Another preferred embodiment)

[0036] In addition, the present invention is not limited to the above-described examples, and can be transformed or extended as described below. In the first example, the control circuit 23 performs the control temporarily reducing the level of the on-voltage output from the first output terminal 12a of the DC voltage source 12 while the gate voltage  $V_{ge}$  detected by the gate voltage detecting circuit 22 is between the first set value  $V_{s1}$  and the second set value  $V_{s2}$ . However, the control circuit 23 may temporarily reduce the level of the on-voltage by a predetermined time after the gate voltage  $V_{ge}$  detected by the gate voltage detecting circuit 22 reaches the first set value  $V_{s1}$ . According to a configuration realizing this, it is possible to surely perform the control changing the level of the gate voltage into a low state by a predetermined period when turning on the IGBT 11.

[0037] Moreover, in the first and second examples, the control temporarily reducing the level of the on-voltage output from the first output terminal 12a of the DC voltage source 12 may be terminated after a load current (the collector current  $I_c$ ) flowing into the IGBT 11 reaches a peak value. According to this configuration, it is possible to restrain the generation of surge effectively.

[0038] In the first example, the first set value  $V_{s1}$  may be set to the gate threshold value voltage  $V_{th}$  of the IGBT 11. According to a configuration realizing this, since the control temporarily reducing the level of the on-voltage to be supplied to the gate electrode of the IGBT 11 is performed first when the on-voltage ascends to the gate threshold value voltage  $V_{th}$  of the IGBT 11, that is, when the load current (the collector

current  $I_c$ ) begins to flow into the IGBT 11, it is possible to precisely capture the time point at which the load current begins to flow. As a result, it is possible to surely prevent the load current from flowing suddenly during turning on the IGBT 11.

[0039] In the first example, there is disclosed the configuration performing the detection of the state in which the rate of change of the gate voltage  $V_{ge}$  of the IGBT 11 is temporarily reduced by a mirror effect based on the voltage detected by the gate voltage detecting circuit 22. However, the detection may be performed based on a derivative value of the detecting voltage (the gate voltage of the IGBT 11).

[0040] The configuration of the DC voltage source 12 is not limited to the above examples. For example, the DC voltage source 12 may have a configuration changing the level of the on-voltage output from the first output terminal 12a by selecting serial and parallel states of the plurality of voltage sources by means of the switching device for voltage switching. Moreover, the off-voltage output from the second output terminal 12b of the DC voltage source 12 may be a ground potential level. In this case, the voltage source 15 in the DC voltage source 12 can be omitted. The present invention can also be applied to a driving circuit of an insulated gate type semiconductor switching device (e.g., a MOSFET) besides the IGBT.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Fig. 1 is an electric block diagram showing the first example of the present invention.

Fig. 2 is a circuit diagram of substantial parts.

Fig. 3 is a characteristic curve for explaining operations.

Fig. 4 is a diagram showing the second example of the present invention.

Fig. 5 is a circuit block diagram of an inverter device

for explaining a conventional configuration.

[Reference Numerals]

- 11 IGBT (insulated gate type semiconductor switching device)
- 12 DC voltage source
- 12a the first output terminal
- 12b the second output terminal
- 13-15 voltage source
- 16-17 switching device for voltage switching
- 18 switching device for turn-on
- 19 gate resistor for turn-on
- 20 switching device for turn-off
- 21 gate resistor for turn-off
- 22 gate voltage detecting circuit (voltage detecting means)
- 23-25 control circuit (gate control means)